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July 1980



## ICE ADHESION TESTS ON COATINGS SUBJECTED TO RAIN EROSION

L. David Minsk



U.S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES

U.S. AIR FORCE FLIGHT DYNAMICS LABORATORY



COLD REGIONS RESEARCH AND ENGINEERING LABORATORY HANOVER, NEW HAMPSHIRE U.S.A.

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O. ABSTRACT (Continue as reverse elde if necessary and identify by block number)					
Screening tests to select icephobic coatings displa	aying low ice release forces				
both before and after exposure to rain erosion in a	whirling arm simulator, w				
performed on approximately 60 commercial materials.	A unique linear ball-sli				
shear test apparatus was designed to provide pure s	shear forces. No coating s				
vived the erosion test to give an interfacial shear (103 kPa), an arbitrarily established gool. Severa	strength as low as 15 psi				
TIVE BLUE AND ALDITIONED VERABLECTOR AND CONCRE	1.				
strengths between 30 and 45 psi (207 and 310 kPa) a	il coatings showed shear				

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#### PREFACE

This report was prepared by L. David Minsk, Research Physical Scientist, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. This investigation was funded jointly by the Applied Technology Laboratory, U.S. Army Research and Technology Laboratories, AVRADCOM, Fort Eustis, Virginia, and by the U.S. Air Force Flight Dynamics Laboratory, Wright Aeronautical Center, Wright-Patterson AFB, Ohio.

The report was technically reviewed by Dr. George Ashton and Gunars Abele of CRREL. Glenn Durrell and Alan Saracina assisted in performing the ice shear tests and in preparing specimens.

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#### L.D. Minsk

#### INTRODUCTION

Ice accretion on airfoils seriously interferes with aerodynamic performance, and in the case of helicopter rotor blades asymmetric shedding can cause severe, and sometimes catastrophic, vibration or power loss. Heated surfaces have been developed as a method of controlling ice accretions\*, but the weight penalty for either utility helicopters (such as the UH-1H) or the cruise missile has fostered a search for a passive coating which will exhibit low adhesion to ice and which will survive the surface erosion resulting from raindrop impaction. Nearly 100 commercially available coatings, offered by industry in response to a CRREL survey, were screened for low ice release force on a pristine surface, followed by subjection of the most promising materials to exposure in the rain erosion simulator at the Air Force Materials Laboratory at the Wright Aeronautical Center. The goal was to find a material which would exhibit an interfacial shear stress of 15 psi (103 kPa) after rain erosion; this value was somewhat arbitrarily chosen as the mean of surface shear forces resulting from centrifugal and viscous drag forces.

#### DESCRIPTION OF TEST

Apparatus. A number of laboratories have conducted tests to determine the strength of adhesion of ice to various surfaces. These tests generally apply a shear force to ice specimens frozen onto the test surface within a mold. Unless the specimen mold is constrained to move parallel to the test surface, tensile forces can develop that prevent a pure shear failure, affecting reproducibility of the test and contributing to wide scattering of the data. To ensure pure shear failure, a unique device developed at CRREL by Larry Gould of the Technical Services Division was used in the work reported here. It consists of a Lexan mold mounted on the underside of a plate attached to the upper surface of a linear ball slide (Yankee ball slide model Y3-30, Design Components, Medfield, Massachusetts 02052). The mold is positioned directly above the 2-in. (12.9-cm2) test specimen, and separated from it by a gap of about 0.08 in. (2 mm) (Fig. 1). The force applied to a load block along the ice/substrate interface is measured by a load cell (Interface SM-250 or SM-50) whose output is fed to a strip chart recorder.

Test specimen. The aluminum test block was dimensioned to meet the

<sup>\*</sup> Werner, J.B. (1975) The development of an advanced anti-wing/deicing capability for U.S. Army helicopters. Vol. II. Ice protection system application to the UH-IH helicopter. USAAMRDL-TR-75-34B. Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia. AD A019049.

requirements for mounting on the whirling arm of the Air Force Materials Laboratory rain erosion simulator\*. Block dimensions are 2.435 in. (6.185 cm) base length, 1 in. (2.54 cm) width, and a test surface area of 2 in. (12.9 cm²). A hollow was milled in the base to reduce mass. The test surface was machine-finished with an end mill, and a uniform reproducible surface was obtained by sandblasting with an S.S. White Industrial Abrasive Unit Model C, using  $50-\mu m$  aluminum oxide abrasive powder (White no. 3). The Lexan mold was milled to leave a 2-mm (0.08-in.) lip around the periphery, and a hole was provided on the upper surface for addition of water.

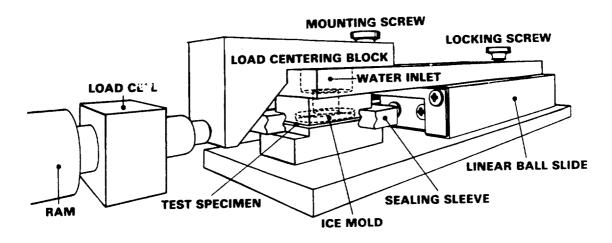


Figure 1. Shear test apparatus.

Sample preparation. The freshly abraded surface of an aluminum specimen was washed with detergent to remove the fine abrasive powder, wiped dry, and then wiped with toluene immediately prior to application of the test coating. Application can be accomplished by spray, wipe, or brush methods, depending on the form of the material; coatings too viscous for spraying were applied by brush in these tests. All specimens with the test coatings were placed in a dust-free enclosure until removed to the coldroom for mounting on the shear test apparatus (Fig. 2).

<u>Test procedure</u>. The aluminum specimen block was mounted on the base plate of the shear test apparatus with two machine screws; the Lexan mold was mounted on the top (sliding) plate with two machine screws. The mold was positioned directly above the specimen, and a silicone rubber gasket (pre-positioned on the mold) was slid over the opening between the two parts to prevent water leakage. The slider was locked with a set screw and the entire apparatus was allowed to stabilize at coldroom temperature  $(-10^{\circ}\text{C})$  for all tests reported here). Following this, deaired, distilled water at

<sup>\*</sup> Hurley, C.J. and G.F. Schmitt, Jr. (1970) Development and calibration of a Mach 1.2 rain erosion test apparatus. Technical Report AFML-TR-70-240, Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

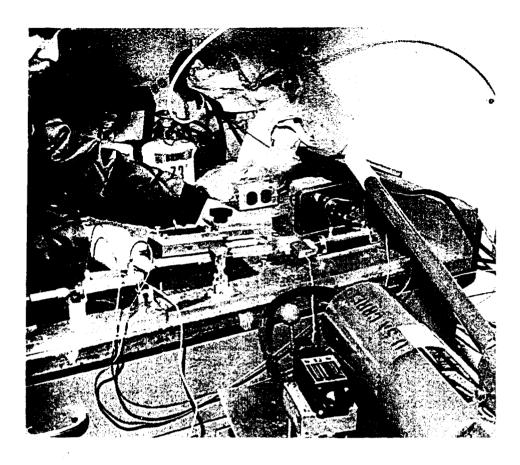


Figure 2. Placing the shear test apparatus on the load application fixture; hydraulic cylinder and strain gauge are to the immediate right of the slide. A separate fixture with hydraulic cylinder and strain gauge, partially visible at left below the technician's hand, was designed for conducting shear tests on flat plates.

room temperature was poured through the holes in both the top plate and the Lexan mold, and the apparatus was tilted slightly in a rolling motion to allow any air trapped in the 1- to 2-mm gap between the specimen and the mold to escape. Sufficient water was added to ensure complete coverage of the test surface, and, if necessary, additional water was added to bring the ice level to the top of the mold. Generally, specimens were prepared in the afternoon and tested the following morning. The frozen specimen in its slide support was carefully placed on the indexing pins of the shear test apparatus, a fixture mounted on the top plate to permit load application in line with the ice/substrate interface, and a hydraulic cylinder was actuated to drive the load cell against the slider. Output was read on a strip chart recorder. Cylinder travel speed was controlled by a flow-control valve (Sperry Vickers Model FCG) and was adjusted for a speed of 0.1 in./s (0.25 cm/s).

Rain erosion. Specimens in most tests were exposed for 10 minutes at a speed of 500 mph (805 km/hr) to rainfall at a rate of 1 in./hr (2.54 cm/hr), with a median droplet size of 1.8 mm (0.071 in.). Most coatings

failed this severe condition; therefore one group of specimens was exposed to a 300-mph (483-km/hr) speed for 5 minutes. This group of tests was not considered valid, however, since the rain erosion simulator had been calibrated for droplet impaction conditions occurring at 500 mph, and it was not known how many of the droplets actually struck the specimen at the lower speed. Nonetheless, the ice release forces measured at the lower speed were tabulated in the results.



Figure 3. Appearance of test specimens following ice release. Adhesive failures left a clean surface; high energy surfaces (those to which ice bonded strongly) failed partially cohesively, exemplified by the specimen in lower center on which some ice can be seen.

#### EXPERIMENTAL RESULTS

Two replicates of each test surface were run for both the pristine coatings and for those that were subjected to the rain erosion test. This small number did not permit any valid statistical tests of dispersion, but were justified on the grounds that a large number of candidate coatings needed to be screened and a selection made in a rather short time for three or four coatings to be used on in-flight tests. The ice release values, expressed as shear stress in psi, are presented in Table 1. Ice did not break cleanly from all test surfaces; some specimens exhibited cohesional failure, with a portion of the ice remaining on the surface. These are indicated by a listing of the proportion of the surface remaining ice-covered in the columns titled "Ice Residue" in Table 1. Figure 3 shows typical ice failures, with ice residues visible in the two specimens at the lower right.

Table 1. Ice release shear stress values for new and rain-eroded icephobic coatings.

			500	500 mph, erosion				
		300 mph, 6	erosion	Trial 1	Trial	2		
Coating	Shear stress new (psi)	Shear stres (psi)	ss Ice residue	Shear stress (psi)	Shear stress (psi)	Ice residue		
Allied Chemical CM-1	>19							
Armstrong E-72300-3N	< 1	43	1/3	65				
Carborundum Dilectrix	51	54	1/8					
Contour XA-1876	< 1							
Cramolin Carbo Spray	53							
Cramolin Plastik	78		. (0					
Dexter 0709-A05M	< 1	. 68	1/8	81*				
Dexter 0709 Micolon 'ow Corning E-2460-40-1	>19 l < 1	44	1/2	60				
ow Corning E-3382-100	< 1	. 55	1/4	52				
Dow Corning R-4-3117	1	. 33	-, .	80*				
Dow Corning 09-6500MST	1.5	54	1/8	57				
Du Pont Vydax AR	68							
Du Pont Vydax 550	75							
Easton STST	40							
GE G661 GE G666	1 3			44				
GE G671	2			78				
GE 117-8441-B	< 1	69		42				
GE 117-8499	< 1			81*				
GE 124-5964	45							
GE RTV 158	15			45	22	1/8		
GE RTV 619	501	20	1/4		28	1/8		
GE SS 4044 GE SS 4124	50*							
GE SS 4191	50* 30							
GE Viscasil 100,000	< 1							
General PG 405	< 1	65	1/10	83*				
Greenchem MR 218	< 1							
Greenchem MR 515	< 1							
Groendyk 8604 Kantstik LM	11 45							
Kro-Lon	10							
MES-5	47			¥				
Meyer Sno-Flo	47			•				
м & н 1604	50							
Miller-Stephenson MS 12								
Miller-Stephenson MS 13 Peterson TFE #4	6 57 50							
Phillips Ryton PR-01	> 9	53	1/8					
RAE 127L	< 1	63	1/3	55				
Repcon	25		-, -					
Rilsan Nylon 11	17							
Rilsan RDP-21	< 1							
Seize-no-More	< 1	, -	1.40	81*				
StanChem 85X-162 Sterling Astrocoat 7100	8 + >18	45	1/3	32				
SWS 951	2							
SWS Silgan H-621	1							
SWS Silgan H-622	1	54	1/3					
SWS Silgan J-500	2	< 1		46	23	clean		
SWS Silgan J-501	28							
3M SJ-8581	54	48	1/8	31				
Tuf-lube Tellon Tullanox LC410	18 66							
Union Carbide Grafeil	48							
Vulkem Urethane #450	-19							
Xylan 1010	15							
Xylan 1014	· 1							
Xylan 1052	2							
- Xylan 8450 - Bare metal (Aluminum) -	+ - <del>1</del> - 81≄							
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Supplementing this information is a table of important properties of the materials tested (Appendix A) and a list of the manufacturers (Appendix B).

#### RECOMMENDATIONS

Coatings recommended for further laboratory and field evaluation are:

General Electric 117-8441-B General Electric RTV 158 General Electric RTV 619 SWS Silgan J-500 StanChem 85X-162 3M 8J-8581

Several other coatings with higher shear strength values are recommended for further testing with a larger number of replicates in order to obtain statistically significant values. These include:

> Dow Corning E-2460-40-1 Dow Corning E-3382-10C Dow Corning 09-6500 MST RAE 127L

All the icephobic coatings listed above, with two exceptions, are silicone-based polymers. The exceptions are RAE 127L, a wax paste, and 3M SJ-8581, a polyurethane tape. The polyurethane test results were unexpected; the rain-eroded surface displayed lower values of ice release shear strength than the fresh surface. Though this could be a real effect resulting from surface modification, such as cold flow under the peening action of droplet impact, more ice release tests and surface characterization should be undertaken.

### APPENDIX A: PROPERTIES OF COATINGS TESTED

FLASH	Non- flam- mable	100F (38C)		182°C	180°C			45°F		None
CURE		hard 24 100F hr, (380 fully cured 7 days,		None				4 hrs (open air)		
DILUENTS (SOLVENTS)		Phosphoric acid (10%), methylene chloride	Acetone	Trichloro- trifluoro- ethane	Trichloro- trifluoro- ethane			Reducer 255-C-157		None
DILUTION OF MIX		4 polyol, l isocy- anate						4A:1B		None
APPLICATION METHOD	Powder coating	Brush, spray, roller	Dip, spray	Spray	Spray	Spray		Spray, brush		
PENETRATION										
VISCOSITY	J-9-			. 694 cp						None
COMPOSITION	Hexafluoro iso- butylene- vinylidene fluoride copolymer	2-part aliphatic polyurethane	Ероху	Cramolin (red) fluid, Freon TP	59% trichlorotri- fluoroethane,41% acrylic resin	Graphite		Acrylic urethane enamel, 2-part		Teflon TFE
FORM	Powder coating	Lfq.	Coated	L14.	Liq.	Lfq.	i.lq.	Paint	Coated	Sheet
MANUFACTURER	Allied Chemical Company	American Technical Industries	Armstrong Products Co.	Calg Laboratories Inc.	Calg Laboratories Inc.	Calg Laboratories inc.	Contour Chemical Company	Cook Paint and Vareish Co.	Dexter Corporation	Dilectrix Corp.
PRODUCE NAME	C>F-1	ATI-KOLE 550	E-72300-83	Cramolin 'R'	Cramolin Plastik	Cramolin Graphice	XA-1876	Acrothane Naite 975- W-426	6709-A05M Sackbartom Black 4109- W02M Mcolon IV-W black	Ollectrix

FLASH	None	None		None		P-M closed- cup,500F (260C)	None	None		ir)
DILUENTS (SOLVENTS)	MEK, acetone; chlorinated solvents fairly good, aromatics only fair	Toluene and None acetone	Toluene, ketones, heptane, xylene, chlorinated hydrocarbons	Water			1,1,1, tri- None chloroethane, mineral spirits	Naphtha, 1-2 day None methylethyl ar 25oC ketone, tri- 15 min at chloroethy- 150oC lene		l min (open air)
DILUTION OR MIX		None	1:3 sili- cone; dilu- ent	None or 1:1						
APPLICATION METHOD	Spray	Brush, wipe, spray	Brush, wipe	Wipe, brush		Brush, wipe	Brush, spray, dip	Spray, brush, dip		Spray, brush wipe
PENETRATION	250-300						260-320			
VISCOSITY	d ×ane	ē	1 1	ulston cone	ai.	100,000 cs		500 cps		
COMPOSITION	Silica-thickened trifluoropropyl- methyl polysiloxane	Cyanoethanol silicone and dimethyl silicone	Toluene soln of a curable dimethyl polysiloxane	30% cationic emulsion of special silicone fluid	Silicone release	Polydimethyl- siloxane	Polydimethyl- siloxane	Silicone	not stated	Silicone
FORM	Grease	. L1q.	L1q.	Líq.	Liq.	Liq.	Grease	Paste	Coared plate	Liq. Liq.
MANUFACTURER	General Electric Grease Co.	General Electric L1q. Co.	SS419 (SS4192C) General Electric Liq. catalyst Co. and SS45259C accelerator)	General Electric Liq. Co.	General Electric Liq. Co.	General Electric Co.	General Electric Grease Co.	General Electric Co.	General Magnaplate	Greenchem Products
PRODUCT NAME	117-8499-B	117-8441-B	SS419 (SS4192C) catalyst and SS45259C accelerator)	124-5964	884290	Viscasil 100,000	GE 697	RTV 619	Tufram PG 405	MR 218 MR 515

IX (SOLVENTS) CURE POINT	40% solids Cellosolve 24 hr @		168F (75C)		Nona None				4-6 hrs	<pre>1:1 (spray) Non-polar, None N.A. e.g. toluene (grease)</pre>	oln hexane 12 hr 250C 25C (77F) (400F) 502 RH TAG closed	1:1 (spray) Non-polar or None chlorinated, e.g., hexane; also aromatics, No polar solvents, no MEK.
TON DILUTION OF MIX					i pe			i pe None	ray		brush 10% soln	
APPLICATION METHOD	Spray, dip,				Brush, wipe	Spray		Spray, wipe	Brush, spray	Brush, wipe, trowel (spray diluted soln)	Wife or brush	Brush, wipe, trowel (spray diluted soln)
PENETRATION		*			210-230					200-300	×.×.	250-300
VISCOSITY									45-55			<u>.</u>
COMPOSITION	Silicone resin	Cationic silicone	2-part cationic silicone oil		Stlicone	Fluorotelomer dispersion in Freon IF	Fluorotelomer	Hard and soft waxes emulsified in water with small amt. HMM silicone oil and phosphate ester	Urethane	Silica-filled polydimethyl siloxane fluid	Acetoxy-cure silicone	Mea-filled silica- thickened methyl alkyl silicone
FORI	Liq.	Liq.	Liq.	Liq.	Paste	Liq.	Liq.	Paste	Liq.	c Paste	c Pante	c Grease
MANUFACTURER	Dow Corning	Dow Corning	Dow Corning	Вом Согиля	Dow Corning	E.I. du Pont de Nemours & Co.	duPont	Easton R.S. Corp.	Essex Chemical Corp.	General Electric Paste Co.	General Electric Paste Co.	General Electric Grease Co.
PRODUCT NAME	R-4-3117	E-2460-40-1	E-3382-100	1SK 0059-60	DC 5 compound	Vydax 550	Vydax AR	STST	Betaeote 91	6 661	RTV 158	G 671

FLASH					None	None	Non- flam- mable	_	30 30 455°C			
CURE							Fast dry-	7 days (21C) (21C) 40 min (150F) (66C)	72 hrs at 315 C, 30 min at 45			None
DILUENTS (SOLVENTS)												Mineral
DILUTION OR HIX		None		None	None	None		afx 1:1 A:B				None
APPLICATION METHOD		Spray, squeegee, roller, brush, trowel	Spray	Brush, spray	Spray	Spray	Brush, spray, dip	Brush, roller spray	Spray	Spray		
PENETRATION	.*											
VISCOSITY	น้ำ	rethane			AR	AR						
COMPOSITION	Silicone rubber, 60 durometer	Modified polyurethane rubber	Silicone		Contains Vydax AR	Contains Vydax AR	Fluorocarbon	2-part epoxy with Teflon particles	Polyphenylene sulfide		Polyamide	Polyamide
FORM	Sheet	Coated	Liq.	Paint	Liq.	Liq.			Coated	Liq.	Coated plate	
MANUFACTURER	Groendyk	The Master Mechanics Co.	msh Laboratories, Inc.	heyer Products Co. Paint	Miller-Stephenson Liq. Chemical Co.	Miller-Stephenson Chemical Co.	Miller-Stephenson Chemical Co.	Peterson Chemical Corp.	Phillips Chemical	Rever	Rilsan Corp.	Rilsan Corp.
PRODUCT NAME	8604 Rubber	Vulkem 450	1604 Ice repellent	Sno-Flo	MS-122	MS-136	MS-S-143	TFE no. 4	Ryton PR-01	M.F.S. 5	RDP-21/Rilprim P-104	Nylon 11

DILUENTS FLASH (SOLVENTS) CURE POINT	Water 10 sec gel time	Water None	MEK, butyl 30 min @ 105- acetate, 250F 110F butyl alcohol, TAS xylene, toluene open or 1,1,1-tri- cup	85/15 methyl- 45-60 min ethyl ketone/ at 50% RH dimethylformamide		7 days a 77F (25C) 502 RH	24 hr (3 510F 77F (25 C) 50Z RH	24 hrs	24 hr (7 days complete)	24 hrs	NA NA NA
OR MIX (	None	None	5:1 diluent: MEK, butyl silicone acetate, butyl alco xylene, to or 1,1-1-t	25-50% Astrocoat e thinner d					20:1,4622: CN by wt.	20:1 CN catalyst	N.
APPLICATION METHOD	Brush	Brush, wipe, spray	Spray	Spray, brush	Spras		Sprav, dip, brush	Spray, dfp. brush	Flow	Flow	tape
PENETRATION											X.
VISCOSITY		led	20-26 sec. 7 <sub>2</sub> g 17cF				lon	300 polse	15,000 cp	30,000 cp	V.
COMPOSITION	Gelled wax paste	Mixture of fatty acid and esterified organic acid in aqueous soln	Silicone, 42% solids	Urethane		SH feene	Silicone dispersion	Silicone	2-part silicone polymer	2-part silicone polymer	Polyurethane film, 0.014" thick
FORM		lucts		36. 30.		•daog	Corp.	Corp.	Corp.	Corp.	
MANUFACTURER	Royal Aircraft Establishment	Specialty Products Co.	StanChem, Inc.	Sterling Lacquer Nanufacturing Co.	Stoner's Ink	SES Stitcomes Corp.	SWS SILicones Corp.	SWS SIlicones Corp.	SWS Silicones Corp.	SWS Silicones Corp.	3M Company
PRODUCT NAME		Kant Stik LM	StanChem 85X-162 clear	Astrocoat 7100	Seize-no-more	SKS 951	Stlgan .1-501	S11gan J-500	Silgan H-622	Silgan H-621/ CN cat.	8.1-8581

ON DILUENTS FLASH X (SOLVENTS) CURE POINT				Isopropyl 1 min 70F alcohol (21C)		ethyl acetate, 32-40 min dimethyl \$284-650F formamide (140-344C)	ethyl acetate (same) dimethyl forma- mide			
DILUTION OR MIX										
APPLICATION METHOD		Electolytic plating		Wipe	Spray	Spray	Spray	Spray	Spray	
PENETRATION										
VISCOSITY				Ų						
COMPOSITION	Polyurethane tape	Chrome/Teflon	Fumed amorphous silica powder and organic silicone-like compound in liquid hydrocarbon	Activated isomeric polymers	Fluorocarbon	Fluorocarbon/ polyimide	Fluorocarbon/ epoxy	Fluorocarbon		Graphite
FORM	Sheet	Coated	L1q.		Coated plate	Coated	Coated plate	Coated	Liq.	Sheet
MANUFACTURER	3M Company	TFB, Inc.	Tulco, Inc.	Unelko Corp.	Whitford Corp.				Xim Products	Union Carbide Corp.
PRODUCT NAME	SJ-8561	Kro-Lon	Tullanox LC 410	Repcon rain repellent(for glass and plastic)	Xylan 8450	Xylan 1014	Xylan 1052	Xylan 1010	Nim Glid Air	Grafoil

#### APPENDIX B: MANUFACTURERS OF COATINGS TESTED

Allied Chemical Co. P.O. Box 1057R Morristown, NJ 07960 201-455-2000

American Technical Industries P.O. Box 399
Stoughton, MA 02072
617-828-4480

Armstrong Products Company P.O. Box 657
Warsaw, IN 46580
219-267-3226

Caig Laboratories
P.O. Box 64
Escondido, CA 92025
714-743-7143

Dilectrix Corporation 69 Allen Blvd. Farmingdale, LI, NY 11735 516-249-6419

Contour Chemical Company 3 Draper Street Woburn, MA 01801 617-935-5910

Cook Paint and Varnish P.O. Box 389
Kansas City, MO 64141
816-471-4800

The Dexter Corporation
Midland Division
One Elm Street
Windsor Locks, CT 06096
203-623-9801

Dow Corning Corporation
Fluids and Lubricants Research
Midland, MI 48640
Mr. Joseph W.Keil
517-496-4407

E.I. du Pont de Nemours & Co., Inc. Organic Chemical Department Dyes and Chemicals Division Wilmington, DE 19898 302-774-2421

Easton R.S. Corp. 4907 Farragut Road Brooklyn, NY 212-629-0920

Essex Chemical Corporation Jamestown Finishes Division 125 Blackstone Avenue Jamestown, NY 14701 716-665-6313

Frekote Inc. P.O. Box 825 Boca Raton, FL 33432 305-395-3083

General Electric Company Silicone Products Department Waterford, NY 12188 Mr. John H. Wright 518-237-3330

General Magnaplate Corporation 1331 U.S. Route 1 Linden, NJ 07036 201-862-6200

Greenchem Products 3035 Hartzell Street Wilmette, IL 60091 312-251-0507

Groendyk Manufacturing Company P.O. Box 276
Buchanan, VA 24066
703-254-1010

MAMECO International 4475 East 175th Street Cleveland, OH 44128 216-752-4400

Meyer Products, Inc. 18513 Euclid Avenue Cleveland, OH 44112 216-486-1313 M & H Laboratories 2705 Archer Ave. Chicago, IL 60608 312-842-2132

Miller-Stephenson Chemical Co., Inc. P.O. Box 950
Danbury, CT 06810
203-743-4447

Peterson Chemical Corporation Box 191 Sheboygan, WI 53081 414-458-5555

Phillips Chemical Company Plastics Technical Center Bartlesville, OK 74004 918-661-6600

Rever Manufacturing Corp. 32470 Gratiot Roseville, MI 48066

Royal Aircraft Establishment Materials Department Bldg. R.178 Farnborough, Herts, England Mr. J. H. Sewell

Specialty Products
15 Exchange Place
Jersey City, NJ 07302
201-434-4700

StanChem Inc.
East Berlin, CT 06023
Frank E. Flood
203-828-0571

Sterling Lacquer Manufacturing Company 3150 Brannon Ave.
St. Louis, MO 63139
314-776-4450

Stoner's Ink Quarryville, PA 17566 717-786-7355 SWS Silicones Corporation P.O. Box 428 Adrian, MI 49221 517-263-5711

TFB, Inc. 1900 South Navajo Street Denver, CO 80223 303-936-7101

3M Company
Industrial Specialties Division
St. Paul, MN 55101
Government Representative: D.B. Shepardson
1101-15th St., NW
Washington, DC 20005
202-331-6946

Tulco, Inc.
Talbot Mills Industrial Park
Faulkner Street
North Billerica, MA 01862
617-667-9686

Unelko Corporation 727 E. 110th St. Chicago, II. 60628 312-468-1700

Union Carbide Corporation 230 Park Avenue New York, NY 10017 212-551-2345

Whitford Corporation West Chester, PA 19380 215-436-0600